(1) INFLUENCE OF TRUNK MUSCLE CO-CONTRACTION ON SPINAL CURVATURE DURING SITTING

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Abstract

Background and purpose: Slumped sitting is known to increase disc pressure and aggravate chronic low back pain. In addition, it has been recognized that co-contraction of the deep spine-stabilizing muscles enhances lumbar segmental stability and the sacro-iliac joint. The purpose of this study was to compare the electromyographic (EMG) activity of the trunk muscles and the muscle thickness of the transverse abdominis (TrA) during slumped sitting with the same parameters during co-contraction and investigate how co-contraction influences spinal curvature.

Subjects and methods: Nine healthy male volunteers participated in the study. EMG signals were recorded during both sitting postures. In order to measure the muscle thickness of the TrA, ultrasound images were captured. While the subjects performed both sitting postures, spinal curvature was measured using a hand-held device.

Results: Significantly more activity of the trunk muscles, with the exception of the rectus abdominis muscle, and significantly greater muscle thickness of the TrA were observed during co-contraction of the trunk muscles than during slumped sitting. Co-contraction also resulted in significantly increased lumbar lordosis and a greater sacral angle when compared to slumped sitting.

Conclusion: In this study, it was demonstrated that the instructions given to the subjects on co-contraction of the trunk muscles during sitting increased muscle activity with the exception of the rectus abdominis muscle, muscle thickness of the TrA, and lumbar lordosis.

Key words: Trunk muscle, co-contraction, sitting posture, electromyography, ultrasound images, spinal curvature

1. Introduction

Chronic low back pain (CLBP) is one of the most common and most costly musculoskeletal disorders in modern society [17, 30]. Therefore, more effective prevention and care of CLBP are required.

Regarding spinal posture, Adams et al. [1] reported a loss of lordosis as a predictor of LBP. Risk increases with prolonged and slumped sitting [7, 8]. Increased stress on the spine, which is brought about by an incorrect posture, is considered to be related to CLBP, although the exact etiology of CLBP remains relatively unknown [3]. In the standing posture, the spine is curved in the sagittal plane and shows cervical lordosis, thoracic kyphosis, and lumbar lordosis. When sitting down with the hips and knees flexed, the pelvis rotates backwards and lumbar lordosis decreases [25]. Sitting is said to involve a significantly higher intervertebral disc (IVD) pressure than standing. Slumped sitting is known to increase IVD pressure even further [4, 5]. At the same time, the load on the posterior structures of the spine also increases [40]. The amount of hydrostatic pressure within the IVD nucleus is affected by the manner in which one sits, with the trunk either slumped or erect. Nachemson [42] found that there was 40% more intra-discal pressure at L3 during slumped sitting thanduring erect standing. A slumped sitting posture also increases IVD shear force, posterior annulus tensile force [18], and loading of the posterior ligamentous system [34]. If loading is sustained, it will increase creep in the posterior spinal structures [34], and decrease the ultimate compressive strength of motion segments [15] and nutrition [38]. This may ultimately contribute to disc degeneration [29] and may consequently cause LBP. Furthermore, the flexion-relaxation phenomenon is present during slumped sitting [44], so there is very low active muscular support for the lumbar spine. Because of this very low activation, the load is transmitted by passive structures such as the ligaments and IVD.

Today, many office workers are forced to sit at a desk for several hours while doing their jobs. Most office workers often adopt a relaxed or slumped sitting posture for long periods at their desks. An incorrect and prolonged sitting posture can often overload the spine. Therefore, we have previously suggested that it is very important to teach office workers and the public about correct sitting postures, by activating the trunk muscles such as the lumbar and abdominal muscles [52].

Appropriate trunk muscle contractions are needed to maintain a correct sitting posture and natural lumbar lordosis. Bergmark [9] reported that the muscles controlling the trunk could be classified into 2 groups. The first group includes deep muscles such as the lumbar multifidus, transverse abdominis (TrA), and internal oblique (IO), which are attached to the lumbar vertebrae and provide spine segmental stability. The second group includes superficial and large torque-producing muscles such as the rectus abdominis (RA), external oblique (EO), and thoracic erector spinae, which have no segmental attachment to the lumbar spine. These muscles control gross trunk movement and stabilize the trunk more generally. It is recognized that co-contraction of the deep spine-stabilizing muscles, especially the TrA, IO, and lumbar multifidus, enhances lumbar segmental stability and the sacro-iliac joint [43]. Through the thoracolumbar fascia and control of intra-abdominal pressure, the TrA and IO muscles are considered to stabilize the lumbar spine [14, 21, 51]. Therefore, it is important to teach workers and people in general about the co-contraction of such deep muscles stabilizing the lumbosacral region and maintenance of a correct sitting posture. However, little is known about the influence of co-contraction of the trunk muscles on spinal curvature in the sitting posture. There are still controversies about the relationship between changes in muscle activity, posture alterations, spinal function, and LBP. The relationship between changes in muscle activity and posture alterations has been studied. Some authors have reported that there is a significant increase in the activity of the IO and multifidus muscles in an erect or upright posture, when compared to a slumped or poor posture, during sitting [43, 50]. However, in these studies the activity of the TrA was not measured. There has also been much interest in the stability of the lumbar spine and its relation to LBP [23]. On the other hand, a review on posture reported that there are still controversies and little evidence to support the claims of benefits of ideal posture or the suggestion that poor posture will lead to LBP [44]. Furthermore, while many believe that the "local" muscles are crucial for spine stability, others hypothesize that the "global" muscles play a role. Panjabi et al. [46] suggested that the role the global muscles have in stabilizing the lumbar spine comes from their efficient ability to impact the stiffness of the entire spinal column, opposed to the local muscles that can only act on a few joints. The results of Cholewicki and McGill's biomechanical analysis [12, 33] suggest that no single muscle, local or global, possesses a dominant responsibility for lumbar spine stability.

Although fine-wire electromyography (EMG) has been used successfully to measure the activation of the TrA, it is an invasive procedure. Surface EMG has limited scope for a different reason, in that it is unable to differentiate between TrA and IO muscle activities [35]. Ultrasound imaging (USI) is a noninvasive method for observing changes in the thickness of the abdominal muscles, which reflects muscle activity level. Recent work shows that the measurements of TrA muscle contraction obtained using USI are well correlated with the measurements of isometric contraction of this muscle obtained by fine-wire EMG [37]. In a systematic review, Koppenhaver et al. [27] concluded that it is valid to use USI to measure trunk muscle size and activation during most isometric sub-maximal contractions and that USI appears sensitive to both positive and negative changes. Hodegs et al. [22] reported that USI was less sensitive to changes in abdominal muscle activity. In fact, there are still controversies about the relationship of muscle thickness and activity to the sensitivity of USI. Therefore, there is a limitation when measuring muscle activity using USI.

The purpose of this study was to compare the EMG activity of the trunk muscles and the muscle thickness of the TrA using USI during slumped sitting with the same parameters during co-contraction of the trunk muscles and to investigate how co-contraction influences spinal curvature during sitting. Our findings provide basic information on the sitting posture.

2. Subjects and Methods

2.1. Subjects

Nine male volunteers who were all healthy and had not suffered from any musculoskeletal disorders of the spine, neuromuscular disorders, or general systemic diseases participated in this study. Their mean (± standard deviation) age, height, and weight were 21.8 ± 3.0 years old, 172.4 ± 7.2 cm, and 593.3 ± 97.7 N, respectively. Informed consent was obtained from all the participants.

2.2. Equipment

1) EMG measurement

One experimenter was responsible for collecting the EMG data (Fig. 1-1). After thorough skin preparation, which involved cleansing with alcohol and the use of a skin abrasion technique, disposable silver/silver chloride surface electrodes with a recording diameter of 1 cm (Blue Sensor N-00S, Medicotest A/S, Denmark) were attached. EMG signals were recorded from the RA, EO, IO, lower back extensor muscles (L3), and multifidus muscles on the right side. Electrode placement was based on previous work [6, 16] that noted the position and orientation of the following muscles: the RA (3 cm lateral to the umbilicus), EO (halfway between the anterior-superior iliac spine and the inferior border of the rib cage), IO (approximately midway between the anterior-superior iliac spine and the symphysis pubis, above the inguinal ligament), lower back extensor (L3) (2 cm lateral to the midline running through the L3 spinal process), and multifidus (2 cm lateral to the L4-5 spinal process). Bipolar electrode pairs were placed longitudinally over the muscle belly. The distance between the centers of the 2 electrodes was 2.5 cm. The grounded electrode was placed over the iliac crest and EMG signals, which were continuously recorded during slumped sitting and co-contraction of the trunk muscles during sitting, were amplified, band-pass filtered (10–500 Hz), digitized, and stored by a data acquisition system (Noraxon Myosystem 1200, USA) at a sample frequency of 1000 Hz and a gain factor of 1000. The average muscle activity values over a 5-s sample period for each sitting posture were normalized to MVCs, which were obtained in isometric maximal exertion tasks using a standard manual muscle test described by Hislop et al. [20] (%MVC). Each MVC was held for 5 s and the average EMG activity obtained for each muscle was used to determine the MVC.

2) Ultrasound measurement

A second experimenter was responsible for collecting the USI data (Fig. 1-2). In order to measure the muscle thickness of the TrA, B-mode real-time USI pictures of the lateral abdominal wall were captured, stored, and measured using an Aloka SSD-3500SX system (Aloka Co. Ltd., Japan) with a 10-MHz linear-array transducer. Gel was interposed between the transducer and the skin. The transducer was then placed transversely on the right side of the body, with its center positioned at a point 25 mm anterior to the mid-axillary line at the midpoint between the inferior rib and the iliac crest [32].

3) Spinal curvature measurement

A third experimenter was responsible for collecting the spinal curvature data (Fig. 1-3). Spinal curvature was measured using a skin-surface and hand-held device, the “Spinal Mouse” (Idiag, Switzerland), while performing both sitting postures. The “Mouse” is an easily manageable, computer-assisted, and non-invasive device, which can measure the sagittal curvature and global and segmental ranges of the spine with an accuracy and reliability comparable to that of radiographic analysis [31]. This handy, wheeled device houses an accelerometer, which records distance, angle, and changes of inclination with regard to the plumb line as it is rolled along the length of the spine. It is connected via an analog-digital converter to a base station positioned approximately 1–2 m away and interfaced with a standard personal computer. When manually guided slightly lateral to the midline of the spinal processes of a subject, the system records the outline of the subject's spine from vertebrae C7 to S3 in the sagittal plane. The spinous processes of C7 and S3 are first determined by palpation and marked on the skin surface with a cosmetic pencil. The local angle or inclination relative to a perpendicular line is given at any position by an internal pendulum connected to a potentiometer. Data is sampled every 1.3 mm as the device is rolled along the spine, giving a sampling frequency of 150 Hz. This information is then used to calculate the relative positions of the sacrum and vertebral bodies of the underlying bony spinal column using an intelligent, recursive algorithm. All essential values such as the length of the back, total inclination or reclination, lordosis and kyphosis, segmental inclination, and the position of the pelvis are both graphically and numerically recorded and presented in an easily understandable way. In the current study, the relevant parameters recorded by the "Spinal Mouse" were the thoracic curvature (T1-2 to T11-12), the lumbar curvature (T12-L1 to the sacrum), and the sacral angle. For the thoracic and lumbar curvature, values of less than 0° represent lordosis, while values of more than 0° represent kyphosis. The greater the value, the greater is the degree of kyphosis of the thoracic or lumbar spine. For the sacral angle, values of less than 0° represent the backward inclination of the sacrum, while values of more than 0° represent its forward inclination. A value of 0° indicates an erect position of the sacrum.

2.3. Procedure

The same physical therapist instructed all subjects thoroughly on how to co-contract the trunk muscles while breathing ordinarily without blocking of air by closure of the glottis. The ADIM was used to activate the TrA muscle. The ADIM is known to elicit preferential recruitment of the TrA muscle with minimal activation of the global abdominal muscles [10]. Subjects were instructed to "erect your lower back and draw in your lower abdomen gently." They were asked to slump first and then co-contract the trunk muscles for 5 s each during the sitting posture. EMG, USI, and spinal curvature data were captured simultaneously. To do this, the chief experimenter made a sign by raising his right hand to the other 3 experimenters, to synchronize the 3 measurements, and analyzed the window of each measurement device. Data for each condition were collected twice. The average values of the 2 collections for each condition were used for analysis. The subjects were carefully positioned on a chair with a flat, horizontal surface.

The head of each subject was kept directed forwards with the eyes fixed straight ahead and the arms loosely resting in the lap. The height of the chair was adjusted to ensure that the subjects' thighs were horizontal and the lower legs were vertical. The feet were positioned one shoulder width apart.

2.4. Statistical Analysis

To compare the differences between slumped and co-contraction sitting postures, a paired *t* test was performed on the %MVC from the 5 trunk muscle sites, the muscle thickness of the TrA, and the parameters of spinal curvature, i.e., the thoracic curvature, lumbar curvature, and sacral angle, using SPSS statistical package version 16.0 for Windows. A p value <0.05 was considered statistically significant.

3. Results

The %MVC results from each sitting posture for each of the trunk muscle sites are shown in Table 1. Significantly more activity of the trunk muscles, with the exception of the RA muscle, was observed during co-contraction of the trunk muscles than during slumped sitting. The mean (± standard deviation) TrA muscle thickness during slumped sitting was 4.7 ± 1.2 mm and that during co-contraction was 6.4 ± 1.9 mm. Significantly greater TrA muscle thickness was observed during co-contraction than during slumped sitting. Table 2 shows the parameters of spinal curvature during each sitting posture. Co-contraction of the trunk muscles resulted in significantly increased lumbar lordosis and a greater sacral angle when compared to slumped sitting. The thoracic curvature showed no significant change during either sitting posture. The results indicated that the co-contraction of the trunk muscles during sitting increased lumbar lordosis or decreased lumbar kyphosis, moved the sacrum into an erect position, and had no influence on thoracic kyphosis.

4. Discussion

The instructions given to the subjects on co-contraction of the trunk muscles were expected to activate the trunk muscles, but it was not clarified which muscles are recruited and how spinal curvature is influenced.

The instructions on co-contraction of the trunk muscles resulted in increased EMG activities of the trunk muscles, with the exception of the RA muscle, increased muscle thickness of the TrA, increased lumbar lordosis, and increased sacral angle during sitting. Conversely, instructions on slumped sitting resulted in decreased EMG activity, decreased muscle thickness of the TrA, decreased lumbar lordosis, and decreased sacral angle in the present study. The current authors have previously reported that the same relationship existed in the desk-work posture, which involves sitting in a slightly inclined forward position [52]. This phenomenon has been reported and described as the flexion-relaxation phenomenon [2, 3, 4]. Trunk muscle activity is considered to decrease when the lumbopelvic region becomes dependent on its passive structures such as the bone, vertebral discs, joints, and ligaments, in order to maintain posture against gravity at the end-range of spine flexion.

The relationship between the sitting posture, trunk muscle activity, and CLBP has not been well established [11, 39], but Richardson et al. [49] reported that postural stabilizing muscles such as the lumbar multifidus, IO, and TrA play an important stabilizing role in the lumbopelvic region, increasing physiological and correct lumbar lordosis, and reducing stress on the passive structures of this area. Gresswell et al. [14] considered that these muscles stabilize the lumbar spine through the thoracolumbar fascia and control of intra-abdominal pressure. Hides et al. [19] reported that specific motor dysfunction of these muscles is related to CLBP. Goel et al. [13] demonstrated that a decrease in trunk muscle efficiency increases the load on the lumbar discs and ligaments. This may leave the lumbopelvic region vulnerable to strain, instability, and injury. Prolonged sitting is generally accepted as a substantial risk factor for the development of LBP [26], as it might contribute partially to insufficient nutrition of intervertebral pressure as a result of increased intradiscal pressure [24]. The intradiscal measurements reported by Andersson et al. [3] and Nachemson [41] indicated a lower intradiscal pressure in lumbar lordosis. These studies suggested that a poor prolonged sitting posture might also result in CLBP. Although further investigation is needed to determine the relation between an individual's habitual adoption of a passive posture and dysfunction of the postural muscles, and to clarify how to teach people about correct co-contraction of the trunk muscles and train them to use the correct sitting posture, such instruction might result in more effective load sharing with the active system, decreasing focal and end-range stress on sensitized passive structures. The results of the present study may have implications for motor retraining or instruction on the correct sitting posture among people with specific CLBP. In a systematic review, Prins et al. [48] concluded that LBP may be influenced by the sitting posture in children and adolescents and a correlation has been observed between spinal posture and LBP [45]. In particular, the risk of LBP increases in sedentary workers, with symptoms increasing during sitting for longperiods of time [47]. However, in a more recent systematic review on modifying patterns of movement in people with LBP, Laird et al. [28] concluded that movement-based interventions were infrequently effective for changing observable movement patterns and that a relationship between changes in movement patterns and improvements in pain or activity limitation was also infrequently observed. This suggested that the relationship between changes in muscle activity, posture alterations, spinal function, and LBP is still undefined in literature and inconsistent among authors. Therefore, more investigations on this relationship are required.

In the present study, the activity level of the RA between the 2 sitting postures did not differ significantly. This finding demonstrates that the RA plays a limited role in lumbopelvic stability under low conditions such as sitting. However, even if the activity level of the RA between the 2 sitting postures did not differ significantly, the role of the RA should not be discounted. McGill [36] reported that forces along the RA would progressively increase owing to force contributions from the obliques and the ability to differentially innervate sections of the RA would optimize force transmission. This would balance moments around the lumbar spine and increase efficiency of movement.

5. Conclusion

In this study, we have demonstrated that the instructions given to the subjects on co-contraction of the trunk musclesduring sitting increased muscle activity with the exception of the rectus abdominis muscle, muscle thickness of the TrA, and lumbar lordosis.

Limitation of the study

We were not able to synchronize the 3 measurements mechanically in the present study. Although the 3 experiments were performed in the static posture, there is a possibility of human delay.

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